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Temperature variability influences urban garden plant richness and gardener water use behavior, but not planting decisions

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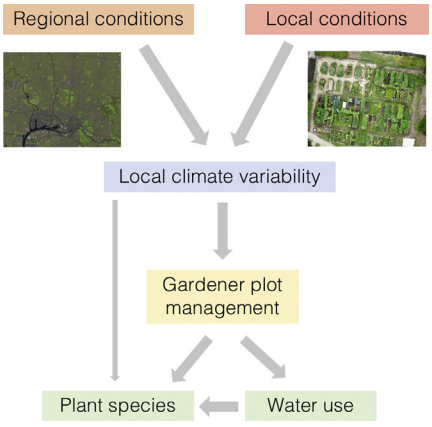
HIGHLIGHTS

- Temperature variability affects urban garden management and resource use.
- Three scale approach examined drivers of variability and social-ecological effects.
- Landscape affects temperature variability to effect plant richness in plots.
- Climate changes prompt gardeners to adjust water use, but not plant selection.
- Plant survival mitigation strategies may still be climate-dependent in cities.

GRAPHICAL ABSTRACT



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ABSTRACT

Urban environments are being subject to increasing temperatures due to the combined effects of global climate change and urban heat. These increased temperatures, coupled with human planting preferences and green space management practices, influence how urban plants grow and survive. Urban community gardens are an increasingly popular land use, and a green space type that is influenced by unique climate-human behavior interactions. Despite ongoing rapid temperature changes in cities, it is unknown how gardeners are adapting to these changes, and to what extent changes influence planting decisions and patterns of urban plant diversity. In this study, we monitored the variation in daily air temperatures and measured plant species richness at the garden and garden plot scale in 11 community gardens in Melbourne, Australia. We surveyed >180 gardeners to better understand the relationships between temperature variation, garden plant species diversity, and gardener management practices. We found that garden scale temperature variability is driven by regional context, and temperatures are more stable in landscapes with higher impervious surface cover. Gardeners agreed that climatic/temperature changes are influencing their watering behavior, but not their plant selection. Instead plant selection is being driven by desired food production. Yet, when comparing two bioregions, temperature did have a measurable relationship with garden plant composition in the region with more temperature variation. Temperature variability negatively related to plant species richness within garden plots, providing evidence that plant survival is related to climate at this scale in such regions. Although gardeners may be able to water more in

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response to regional climate changes, gardeners are unlikely to be able to completely control the effects of temperature on plant survival in more variable conditions. This suggests the inner city with more stable temperatures (albeit potentially hotter for longer due to heat island) may accommodate more species diverse gardens.
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1. Introduction

Climatic gradients often predict species distribution across natural landscapes (Soberon, 2007). Species have temperature and moisture thresholds that allow or inhibit their survival in an ecosystem. Plants in particular are often found along temperature and moisture/precipitation gradients. Consequently, the distribution of plant species are changing with global climate change as temperatures become hotter, and in some places drought events become more extreme (Kelly and Goulden, 2008; Lenoir and Svenning, 2014; Neilson et al., 2005). This can limit plant water availability and thus survival (Breshears et al., 2005; Galiano et al., 2011; Martínez-Vilalta and Piñol, 2002; McDowell et al., 2010). Temperature is a strong predictor of species diversity in natural communities (Grubb, 1977) because of species traits related to species performance (Kleidon and Mooney, 2000; McGill et al., 2006). Climate extremes are having profound impacts on trophic interactions, food webs and the general ecology of regions (Brose et al., 2016; Tylianakis et al., 2008; Walther, 2010; Walther et al., 2002).

Human dominated environments such as cities, are often perceived to be shaped by drivers other than the climatic and biophysical drivers that shape natural landscapes. Human preferences influence resource management decisions that affect plant species distribution beyond natural bioclimatic barriers (Kendal et al., 2018). Vegetation within urban ecosystems is shaped by habitat transformation, as well as unique socioecological filters including biophysical conditions of the urban environment and individual human preference (Pataki et al., 2013; Williams et al., 2008). While, temperature gradients remain a strong filter of urban cultivated plant richness (Kendal et al., 2012a), supplemental irrigation and nutrients can be common in urban residential landscapes (Faeth et al., 2005) and allow some plants preferred by people to thrive through human intervention (Clarke and Jenerette, 2015; Hope et al., 2003; Jenerette et al., 2016). Within urban ecosystems, the diversity and distribution of plant species are therefore influenced by both environmental filters at a regional scale and local scale as well as through socioecological interactions at the level of the individual (Aronson et al., 2016; Avolio et al., 2015; Williams et al., 2008).

Changes in temperature and precipitation due to global climate change (Freitag et al., 2018) and intensifying urban heat island effects (Oke, 1973) are therefore likely to affect the composition and diversity of urban gardens (Eriksen-Hamel and Danso, 2010). Irrespective of human intervention in the form of irrigation and fertilizer application, higher temperatures and evapotranspiration are likely to affect the plant species grown in urban environments where they are sensitive to heat and water stress (Albrecht and Haider, 2013; Jenerette et al., 2016). In addition, more intense heat and drought may therefore affect the way that people use resources to manage urban green spaces such as gardens (Balling et al., 2008; Jenerette et al., 2013).

Urban gardens are places where there are unique and complex interactions between temperature, precipitation, watering behavior and plant selection. Urban gardening is a popular past time around the world (Galluzzi et al., 2010; Lawson, 2005; Mougeot, 2000; Zezza and Tasciotti, 2010), and is one of the important ways in which people interact with urban nature (Andersson et al., 2007; Egerer et al., 2018; Okvat and Zautra, 2011) and shape the plants of the urban environment (Galluzzi et al., 2010; Loram et al., 2008; Smith et al., 2006). Ambient temperatures in gardens can be influenced by region-scale urbanization as well as by local garden-scale plant cover, and this can also influence watering behavior (Lin et al., 2018). Greater amount of impervious surface cover surrounding and within urban gardens increases mean and maximum temperatures (Lin et al., 2018), probably because impervious surfaces retain heat due to low albedo (Oke, 1973). In contrast, greater plant ground cover and higher tree density is associated with cooler temperatures and climate mitigation within urban green spaces (Bowler et al., 2010; Gill et al., 2007; Huang et al., 2008; Shashua-bar et al., 2009) including within urban gardens (Piacentini et al., 2014). Local temperatures likely affect the degree to which plants are stressed in this managed environment (Eriksen-Hamel and Danso, 2010), due to effects of temperature on soil moisture retention (Craul, 1992; Pickett et al., 2011). Climate conditions and the potential temperature effects on plants within garden plots may lead gardeners to think that they need to supplement more or less water in response (Avolio et al., 2015; Lin et al., 2018). Yet we know less about how urban temperatures may affect plants cultivated in gardens and their care, as provided by gardeners, within and between gardens. If and how gardener resource management of water and plants within gardens responds to climate variability is critical to urban sustainability.

It is important to assess how climate variability – in the form of temperature fluctuations, extreme heat and drought conditions – may affect the composition and distribution of urban plant communities as cities, and therefore urban plant distributions, expand (Jenerette et al., 2016). It is of particular importance to understand these relationships in urban agroecosystems because variability in temperature, precipitation and their interaction significantly influence crop plant yield (Ray et al., 2015) and consequently ecosystem service provisioning. Increasing temperatures and drought patterns in urban environments will likely negatively affect crop plant productivity and survivorship in urban agriculture (Lobell et al., 2011) because of higher urban temperatures (Eriksen-Hamel and Danso, 2010; Kalnay and Ming, 2003) and water use restrictions on outdoor irrigation implemented during times of drought (Kendal et al., 2012b). If urban gardeners are unable to maintain crop irrigation during heat events, water limitation when plants are most susceptible to evapotranspiration can increase plant vulnerability to sun scorch, disease and pest damage (Gourdji et al., 2013; Meineke et al., 2013). Thus temperature and precipitation variability are still likely to affect species survival and distribution within urban garden plant communities, but there is still much to understand in the context of current urban environmental change.

In this study, we explore the relationships between temperature variability, urban gardener decision making, and plant species richness in garden plots in community gardens across the city of Melbourne, Australia. Community gardens, or gardens managed by a collective of individuals who are each allocated a plot, are popular in urban Melbourne, which is a city known for its temperature and precipitation fluctuations. Climate events over the past decade (e.g., the “Millennium Drought”) indicate that climate patterns are becoming more extreme, in tandem with urbanization (Coutts et al., 2007). However, there is little knowledge of if and how this variability is experienced by green space managers, such as urban gardeners. There is also little knowledge of if and how gardeners are adapting to these proposed changes within their individual garden plots. We aim to fill this research gap through a mixed-method study that uses field-collected measurements of garden temperatures and garden plants at both the garden scale and at the individual plot scale, and quantitative and qualitative survey responses on gardener decision making at an individual level. We focused our study at these multiple scales because individual people do different things at their plots in the same garden. Thus, the plot scale and individual level analyses focus on individual gardener behavior; and the garden scale analyses focus on the response of temperature variability and

garden plants to the local and regional context. Specifically, in this study we asked: 1) Do landscape (regional) and local (garden) factors predict urban garden temperature variability at the garden scale? 2) Can temperature variability in turn explain observed plant species richness in urban gardens at the garden scale or at the plot scale? 3) Does climate variability (temperature, precipitation) influence gardeners' reported planting decisions and water use behavior at an individual level? If not, what factors are important? This study fills an important gap in the understanding of relationships among temperature variability, plant species richness, and gardener behavior across a climatically variable urban environment. This is especially important as climate becomes more variable across the world, and in increasingly popular urban agroecosystems.

2. Methods

2.1. Study system

We worked in 11 community gardens distributed from east to west across the Greater Melbourne Metropolitan area in Victoria, Australia (study area center point: 37°50′8.60″S 145° 2′15.31″E) (Fig. 1). Melbourne is the capital of Victoria, covers 9992.5 km^2 and has approximately 4.7 million residents (City of Melbourne, 2018). Greater Melbourne has the largest and fastest growing population in Australia (2.7% growth from 2016 to 2017) (Australian Bureau of Statistics, 2018). Melbourne's climate is temperate and is generally considered highly variable (Bureau of Meteorology, 2018). The average maximum temperature for summer (December–February) is 25 °C. The Melbourne Metropolitan area spans two major bioregions: the Gippsland Plain in the east of the city and the Victorian Volcanic Plain in the west. Bioregions are a landscape-scale approach to classify Victoria's environment using attributes of climate, geomorphology, geology, soils and vegetation (Victoria State Government, 2018). The Gippsland Plain bioregion is characterized by marine and non-marine Cainozoic sediments and mild temperatures. Mean annual rainfall ranges from 600 to 1100 mm, and daily mean temperature across the bioregion ranges from 9 to 15 °C (Victorian Environmental Assessment, 2010). Much of the vegetation in the region has been disturbed and converted to agricultural land use or (more recently) to urban development. In western Melbourne, the Volcanic Plain bioregion is characterized by Cainozoic volcanic deposits forming a basaltic plain. Mean annual precipitation ranges from 450 to 840 mm, and daily mean temperature across the regions ranges from 12 to 15 °C (Victorian Environmental Assessment, 2010). Much of this landscape has been converted to agricultural (grazing) and urban land uses (Royal Botanic Gardens Victoria, 2017). The central and western neighborhoods of the city are generally more industrial than the eastern neighborhoods due to urbanization history.

The community gardens used in the study were selected and stratified based on the criteria that they were allotment gardens in which individuals or households manage their own plots and were representative of the two bioregions. The gardens are managed by individual gardeners or a committee of gardeners, and overseen by the city council government. To control for differences in bioregions, we focused our study area to the inner suburbs that fell within the Victorian Volcanic Plains and Gippsland Plains bioregions ($n = 5$ in the Volcanic Plain bioregion; $n = 6$ in the Gippsland Plain bioregion). Moreover, we

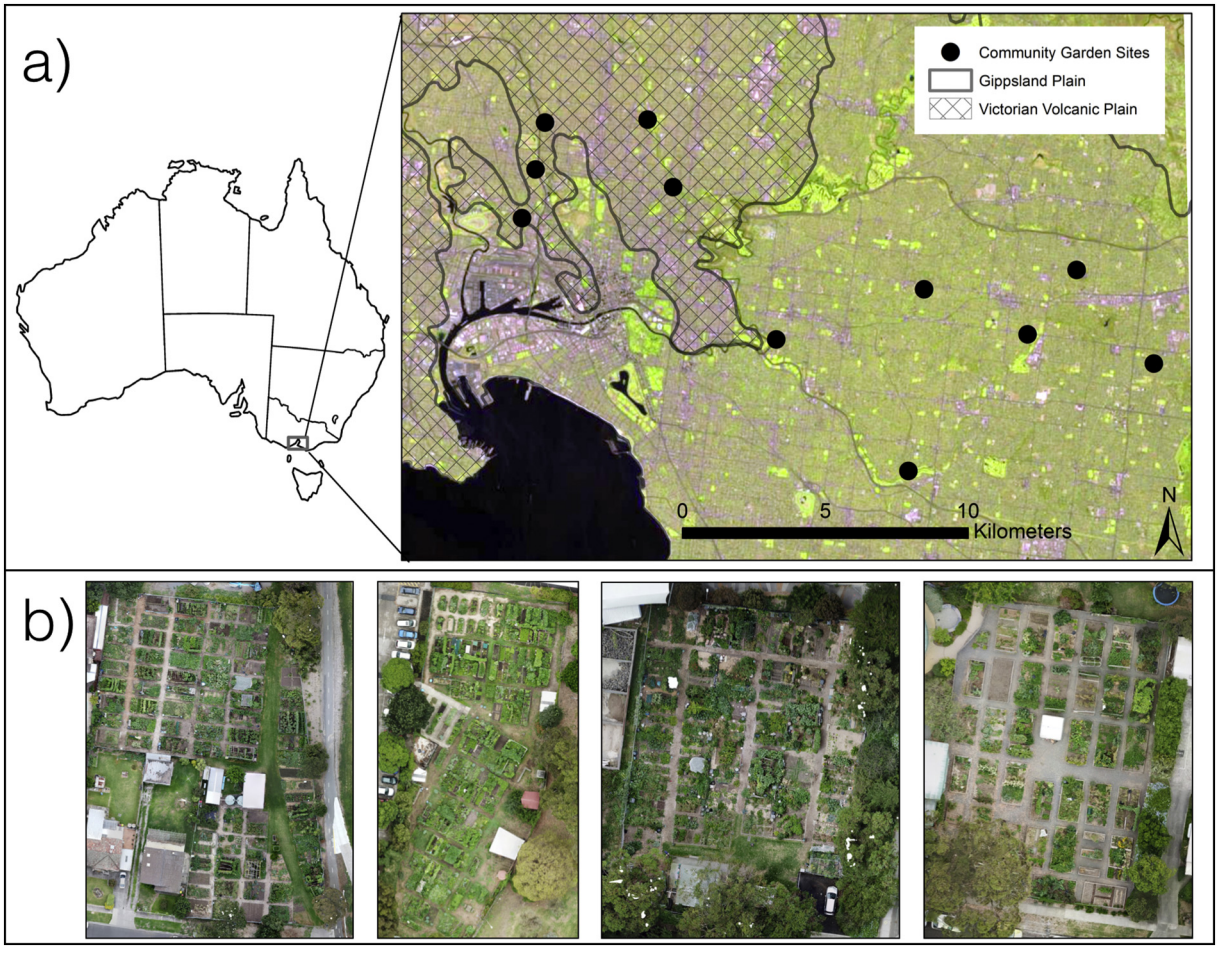

Fig. 1. Locations of the 11 gardens studied within two bioregions in the Greater Melbourne Metropolitan area in Victoria, Australia (a). Aerial images of four of the studied gardens (b). The first two on the left are within the Victorian Volcanic Plain, the two on the right are within the Gippsland Plain.

selected gardens that had 40–60% impervious surface cover surrounding them (see Section 2.2.2) to control for potentially confounding urban landscape influences. The gardens are six to 38 years old, are from 584 to 6801 m^2 in size, and have 25 to 124 allotment plots (Fig. 1).

2.2. Temperature variability and plant species richness

We measured ambient temperatures and plant species richness for individual garden plots and for the whole garden. We refer to these two scales of data collection and data analysis as garden scale and plot scale.

2.2.1. Temperature logging

We placed four temperature loggers (Onset HOBO UA-001-08) in each garden to collect hourly ambient temperature measurements (°C) over the summer sample period (December 15–February 10, 2018). This period is generally when water availability is most limited and temperatures are highest, which are two factors that are associated with high evapotranspiration and stressful conditions for plants in urban environments and warrants targeted research (Faeth et al., 2005). The sample period duration is comparable to other temperature studies in urban agroecosystems (Lin et al., 2018; Piacentini et al., 2014), and was limited by garden access. We worked with garden managers to identify four volunteer gardeners' plots that were spatially distributed within the garden in which to monitor temperature and collect additional plot scale vegetation data. We placed loggers 1.5 m above the plot, and fastened white plastic shields over the loggers to protect loggers from ultraviolet radiation that may damage the sensors and inflate ambient temperatures. We checked and maintained the loggers throughout the survey period to ensure that they were in good working order. Data were downloaded at the end of the survey period and quality checked and cleaned.

For each plot, we calculated the mean and the coefficient of variation (CV) of the average daily temperature. In addition, we calculated the mean temperature CV for each garden from pooled data from the four loggers in each garden.

2.2.2. Plant sampling

We sampled plant species richness and percent cover in each garden across the entire garden (i.e., at the garden scale) and in temperature monitored plots. At the garden scale, we sampled plants within randomly placed 1 × 1 m quadrats along transects placed every 5 m across the garden. Because gardens were of different sizes, we proportionally increased the number of 1 × 1 m quadrats relative to garden size; all gardens had a minimum of eight 1 × 1 m quadrats, and we added one 1 × 1 m quadrat for gardens > 800 m^2 for every additional 500 m^2 (resulting in up to 19 quadrats in the largest garden). We divided the number of quadrats by the number of transects in order to determine how many quadrats to sample along each transect. Within each quadrat, we recorded the species identity of all plants present, estimated the percent cover of plants, and collected information on ground cover characteristics (% grass, straw, mulch, rock, and bare soil) to collect information on local garden characteristics. In addition, we measured the number of trees and shrubs within the garden as a potentially important climate variable (Lin et al., 2018).

Within each monitored plot, we recorded the species identity of all plants present within the entire plot. We also measured the size of the plot, as garden plots were of different sizes. All plant sampling and ground cover surveys were conducted from January 8 to 12, 2018.

To determine landscape-scale plant cover vs urban cover, we collected spatial data of impervious surface cover from Melbourne Water measured at a 1 m spatial resolution (Melbourne Water, 2012) and placed a 1 km buffer around each garden to calculate percent impervious cover within the buffer area.

2.2.3. Analysis

We performed a three-part analysis consisting of multiple models to determine the drivers of temperature variability at the garden scale and plant species richness at both garden and plot scales.

The first analysis at the garden scale aimed to determine whether landscape (regional) or local (garden) factors drive garden temperature variability. Here we used generalized linear models (GLMs) to compare temperature variability among bioregions and among local garden scale factors. We built two sets of garden scale models using pooled data from the four data loggers for each garden. For the first model, the pooled mean temperature CV and the mean daily temperature were the response variables and bioregion was the predictor. We fit the models and ran a post-hoc test using the *glht* function in the *multcomp* package (Hothorn et al., 2008) in the R statistical environment (R Development Core Team, 2016). For the second model, we modeled mean temperature CV and mean temperature by two local scale variables that highly correlated with other local plant and ground cover factors, % grass ground cover (square-root transformed) and garden size (log transformed), and one landscape-scale variable, the % urban impervious surface surrounding the garden (square-root transformed).

The second analysis aimed to evaluate plant species richness at both the garden- and plot scale. We calculated the total number of plant species recorded in each monitored plot and for each garden. To evaluate whether surveys had reached plant species saturation, for the gardens ($n = 11$) and for the garden quadrats ($n = 109$), we calculated sample-based species accumulation curves at the genus level for all of the plants recorded in the garden and in the garden 1 × 1 m quadrats. We used "random" sampling methods in the *speccomm* function in the *vegan* package in R (Oksanen, 2015) to generate mean species accumulation curves and the standard deviation calculated from random permutations of the data without replacement (Colwell et al., 2012). A lomolino model was fit to the exact accumulation (Lomolino, 2001). In addition, we plotted species accumulation curves at the garden and quadrat scale using the same method for each bioregion to compare regional biodiversity under the hypothesis that species richness, if influenced by temperature variability, would be different for the different bioregions.

The third analysis aimed to determine whether temperature variability influences plant species richness at the garden scale and at the plot scale. For the garden-scale model, we built GLMs with the following non-correlated variables: total plant species richness observed in the garden (response), mean temperature CV (predictor), and log-transformed garden size (cofactor). For the plot-scale model, we built GLMs with the following variables: observed plant species richness in the plot (response), mean daily temperature CV in the plot (predictor), and log-transformed plot size (cofactor). We built separate GLMs for each bioregion to control for collinearity among explanatory variables and for bioregion. Models assumed a Poisson error distribution appropriate for count data within a given time and space. The best model was selected as the one with the lowest Akaike information criteria (AIC).

2.3. Influences on gardeners' planting decisions and water use behavior

Concurrently with temperature monitoring and plant sampling, we distributed a survey questionnaire to gardeners in all gardens to collect information on gardener decision making and beliefs concerning climate change. The questionnaire asked gardeners about their watering practices, plant selection, their beliefs about climate (temperature, precipitation), and their beliefs about climate in relation to their watering practices and plant selection.

2.3.1. Gardener questionnaire design

We designed the questionnaire to elicit responses on gardening behaviors (water use, planting decisions), and on general beliefs and attitudes that inform gardener decision making. We designed the survey to

include multiple choice questions, 5-point Likert scale statements, and one open-ended question. The multiple choice questions asked gardeners what influences how much water they use, and what they add to their soils. A series of 13 5-point Likert questions asked gardeners to indicate how strongly they agree with statements on climate change beliefs, and on the relationship between climate and watering and planting practices. A series of six 5-point Likert questions asked gardeners to indicate how important certain plant species attributes are, including: provision of food/usable products, beauty/aesthetics, cultural meaning, low maintenance, native to Australia, and water use/needs. The one open-ended question asked gardeners to elaborate how the climate patterns over the past 12 months influenced their watering and planting practices.

2.3.2. Participant selection and recruitment

The questionnaire was distributed in an online format by the garden managers to the community garden e-mail list, and was also distributed in paper format by the researchers and garden managers opportunistically during garden work days. The questionnaire was provided in English, and we used professional translators or other garden members to assist with questionnaire distribution for non-English speakers. Gardeners received a pack of seeds in gratitude for their participation. We aimed to get as many gardeners as possible per garden, recognizing that our aim to reach all ~700 gardeners (estimated by reported total gardeners from managers) was limited by language (English) and time constraints.

2.3.3. Questionnaire analysis

Questionnaire data was reviewed, cleaned and quality checked before analysis. We calculated summary statistics for gardener practices and Likert question responses to climate questions and water use and plant-related questions. We qualitatively reviewed responses to the open-ended question of how the climate over the previous 12 months has influenced gardening practices. We performed a thematic analysis of the responses. We first reviewed all responses through which we identified three distinct themes: (1) gardeners stated observations on how they believe the climate is changing but did not provide any information about how climate affects their planting or watering practices; (2) gardeners stated changing or adapting their practices to climate changes and how (i.e., through plant selection or through watering) but did not provide any information about how climate is changing; and (3) gardeners stated both observations on climate changes and how they are changing their practices to these respective changes. We then coded each response with the respective theme: “observational,” “behavior change,” or “observational and behavior change.” For the second theme, we further coded whether gardeners reported on their planting, their watering or both planting and watering.

3. Results

3.1. Temperature variability and cultivated species richness

3.1.1. Landscape and local drivers of garden temperature variability

Mean daily temperatures ranged from 22.2 to 23.2 °C at the garden scale and 21.2 to 26.1 °C at the plot scale, whereas temperature variability values (mean temperature CV) ranged from 22.4 to 31.9 at the garden scale and 19.8 to 35.4 at the plot scale. Although average mean temperatures did not differ between the two regions at the garden or the plot scale (Table 1a), mean temperature CV was significantly greater in gardens in the Gippsland Plain bioregion than gardens in the Volcanic Plain bioregion (Fig. 2a). In addition, for garden-scale temperatures, temperature CV was lower in gardens with higher impervious surfaces surrounding them (Fig. 2b), and mean temperatures were lower in larger gardens (Table 1b).

Table 1
GLM analysis at garden- and gardener plot scale of the relationships between mean temperature (C°) and bioregion, and temperature CV and bioregion (a); best model (lowest AIC score) predicting important local and landscape factors of gardens for garden mean temperatures and temperature CV (b). Victorian Volcanic Plain (VVP) is the reference level in (a); temperature is abbreviated to "temp".

a.

Scale	Response	Factor	Estimate	SE	z	P
Garden	Temp CV~	Bioregion (VVP)	−2.88	1.39	−2.07	0.04
	Mean temp~	Bioregion (VVP)	−0.09	0.23	−0.40	0.69
Plot	Temp CV~	Bioregion (VVP)	−2.81	1.25	−2.24	0.03
	Mean temp~	Bioregion (VVP)	−0.14	0.30	−0.48	0.63

b.

Scale	Response	Factor	Estimate	SE	z	P	AIC
Garden	Temp CV~	(Intercept)	58.63	9.88	5.94	<0.001	49.4
		% impervious	−4.40	1.40	−3.15	0.01	
	Mean temp~	(Intercept)	24.90	0.88	28.43	<0.001	8.5
		Garden size (log)	−0.63	0.28	−2.27	0.05	

3.1.2. Plant species richness at the garden- and plot scale

We observed 655 plants of 122 species across 80 genera from the 11 gardens. Over all gardens and over all sampled 1 × 1 m quadrats, the species accumulation curves did not asymptote to indicate species saturation (Fig. 3). Likewise, species accumulation curves did not asymptote individually in the two bioregions at the garden or quadrat scale. Curves for both regions followed similar trajectories. At the garden scale, plant species richness significantly increased with garden size (Table 2). At the plot scale, plant species richness was positively correlated with plot size in gardens in the Victorian Volcanic Plain region but not in the Gippsland Plain (Table 2; Fig. 4b).

3.1.3. Influence of temperature variability on plant species richness

There was no relationship between plant richness and temperature variables or bioregion at the garden scale. At the plot scale, plant species richness was negatively correlated with higher temperature CV in gardens in the Gippsland Plain but not in the Victorian Volcanic Plain bioregion (Table 2; Fig. 4a).

3.2. Influences on gardeners' planting decisions and water use behavior

The urban climate of Melbourne influences the gardening of the 189 community gardeners we surveyed. We highlight the main results and themes from the survey questionnaire using quotes from the open-ended question and proportions (%) determined from Likert statements and multiple choice questions.

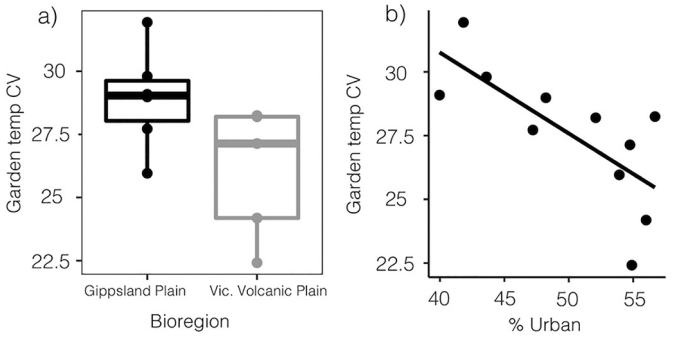

Fig. 2. Garden ambient temperature variation (CV) was greater in the Gippsland Plain bioregion (a), and in gardens surrounded by less urban impervious surface (%) (b).

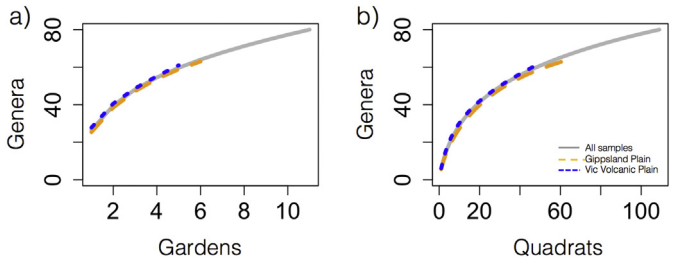

Fig. 3. Species accumulation curves for genera sampled from the gardens (a) and within the sampled quadrats (b). Gray lines indicate for all pooled samples, large orange dashes represent the Gippsland Plain bioregion, and small blue dots represent the Volcanic Plain bioregion. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

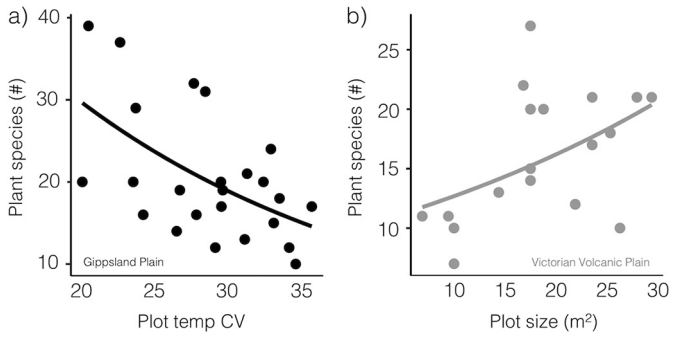

Fig. 4. Relationship between measured plant species richness within monitored gardener plots and ambient temperature variability (plot temperature CV) in the Gippsland Plain bioregion (a), and gardener plot size (meter squared; log scaled axis) in the Victorian Volcanic Plain (b). Lines are Poisson regressions.

3.2.1. Gardener perceptions of climate in relation to gardening

Overall gardeners described the climate as both variable or as mild over the past year. Some gardeners reported that it was a "mild season" or that "we haven't had drought this year," and some of these gardeners went on to say that the climate has not affected their gardening (11%). However, 61% of gardeners strongly agreed that the climate is changing (in the Likert statements), and gardeners described the climate as unpredictable (in open-ended responses). One gardener described the climate as "increasingly less predictable and less consistent - warm periods when should be cold, and cold periods when should be hot. Everything to excess frequently." Another gardener reported: "Easterly systems moving into Gippsland appear to [be] becoming more frequent and heavier and may reach us. Prolonged periods of higher temperatures in summer. The autumn break seems to be later and less reliable." This gardener went on to share that they believe: "our climate appears to be changing but has yet to settle to a new pattern to meet a warming atmosphere. I feel that in the future it will be less pleasant to live in Melbourne and that traditional vegetable and fruit growing will be forced to change." Thus this gardener links climate changes in the city to broader outcomes for urban life and urban agriculture.

Gardeners are in strong agreement that both natural rainfall and temperature influence the way that garden plants grow (>80% of gardeners), and tended to agree that they are concerned about the effect of increasing heat (50%) and drought (50%) on their gardens, and that drought will cause water scarcity (60%). Gardeners reported incidences of and worry about plant mortality due to extreme climate events. To illustrate, one gardener shared: "I have been concerned about whether my plants will survive or if I will lose harvest due to severe weather." Other gardeners thought that "the hot days seem harsher on veggies now," and observed "the blistering sun burning/frying foliage." One gardener reported that they "lost all [their] tomatoes with the heat," while another gardener reported that high humidity caused tomato wilt. However, the same gardener stated that "other plants like cucumber have done really well." Thus while some vegetables were reported to fail to grow or produce, others may survive climate extremes.

3.2.2. Gardener watering behavior in relation to climate

Gardeners reported that their water use is most influenced by their beliefs on what plants need (89%) and the climate (76%). Some gardeners also reported that garden rules influence their watering (37%) as well as the soil conditions, water conservation efforts, and time constraints (<10%). A majority of gardeners agreed that they change the way that they water in response to the climate (50%) and specifically based on the temperature (60%). To the open-ended question, gardeners report changing both the times and the regularity of watering to maintain plants in response to inconsistent climate patterns. Gardeners in this group said that they are: "increasing their watering due to the 40 degree days we had"; "increasing watering due to higher temperatures over longer periods"; and doing "more frequent watering due to increased temperatures." Gardeners reported that they are "more conscientious about watering to keep plants alive." Described by another gardener, "I pay more attention to the weather report and respond quicker to dry and hot weather […] I am more conscientious of our plants' needs." However, other gardeners reported that they have used less water or changed their watering method due to more rainfall over the year: "we have had some extreme rainfall so I haven't watered as much"; "more rainfall so less watering, but heavier watering less frequently"; and, "used less mulch, more subsoil watering."

3.2.3. Gardener plant selection in relation to climate

Only 30% of gardeners agreed that they change the plants that they grow in response to climatic changes in precipitation and temperature (Likert statements), and only 9% of gardeners described how they are changing their planting practices to climate changes (open-ended question). Most gardeners disagreed that past drought experiences influence the plants that they currently plant. Rather, the plant attribute most important for gardeners is the provision of food/usable products (90% of gardeners ranked "important" or "very important") (Fig. 5). This attribute was followed by low maintenance (35%), beauty/aesthetics

Table 2
GLM analysis at garden scale (a) and gardener plot scale (b) of the relationship between plant species richness and temperature CV, and garden size or plot size for each bioregion, respectively.

Scale	Bioregion	Response	Predictor	Estimate	SE	z	P	AIC
a. Garden	All	Plant species #~	(Intercept)	2.04	0.91	2.25	0.02	69.9
			Temp CV	−0.02	0.02	−0.76	0.45	
			Garden size (log)	0.58	0.17	3.49	<0.001	
b. Plot	Gippsland Plain	Plant species #~	(Intercept)	3.93	0.46	8.45	<0.001	161.6
			Temp CV	−0.05	0.01	−4.45	<0.001	
			Plot size (log)	0.46	0.26	1.78	0.08	
	Victorian Volcanic Plain	Plant species #~	(Intercept)	2.46	0.44	5.62	<0.001	117.8
			Temp CV	−0.01	0.01	−0.78	0.44	
			Plot size (log)	0.60	0.23	2.63	0.01	

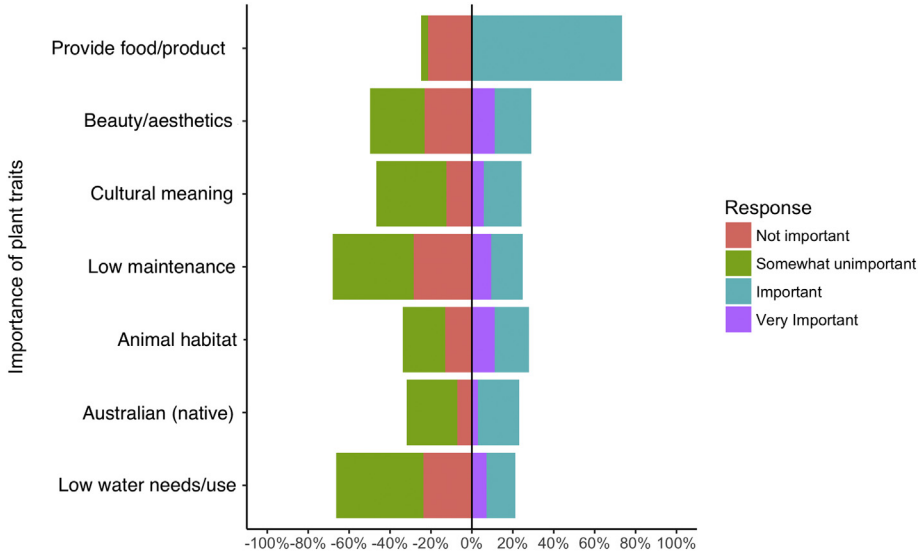

Fig. 5. Responses to Likert scale questions asking how important plant attributes are to gardeners' plant selection. The y-axis shows plant attributes and the x-axis indicates the percentage of gardeners with a strong directional response. Here, positive values indicate a positive response (i.e., attribute is important), negative values indicate a negative response (i.e., attribute is relatively unimportant), and neutral non-directional responses (i.e., do not agree nor disagree) are at zero.

(33%), water use/needs (30%), habitat for animals/insects (22%), cultural meaning (18%), and native to Australia (9%).

3.2.4. Diverse responses to climatic changes and associated challenges

Few gardeners (4%) agreed that they are changing both planting and watering practices in response to the climate. One of these gardeners reported: "I have not planted any plants which are too temperature sensitive. I try to minimize the amount of water I use in the garden by less frequent but deeper watering, mulching, etc." Another gardener shared that: "I water more often as I feel the water evaporates more quickly. I also mulch more now to help keep the soil moist. I choose plants that can tolerate harsher conditions. I take care to protect myself from sunburn so I try to garden in the morning or early evening." Thus this gardener shared how the climate influences their water use behavior and plant selection, as well as when they use the garden. Like this gardener, others reported increased mulching to reduce water loss and watering needs: "I am now purchasing twice the amount of mulch to try to retain more moisture in the soil and moderate soil temperature." In addition to protecting soils by mulching, gardeners reported adding shade cloth to protect their plants from solar radiation.

Last, some gardeners indicated that learning how to garden in a changing climate is a challenging process. In the words of one gardener: "I find the garden more vulnerable and responds if I fail to care properly for it. I can be hit and miss at times, and feel my routine is not right yet." Another gardener stated: "It's been unpredictable, making it hard to know when to water […] We've had some very wet periods […] also some very hot periods, which has been a challenge to manage." One gardener described how plant establishment is increasingly challenging: "Planting new plants requires more watering in and care time to establish. The late heat in late 2017 meant tomatoes didn't establish until much later. Direct sowing is more challenging with less reliable rainfall. We have had to rely more on seedlings."

4. Discussion

Temperature variability within urban gardens is largely driven by landscape context, and this variability is challenging gardeners to adapt their behaviors. Temperature variability shapes plant species richness at the scale of an individual's plot, in addition to the area available for them to garden, but this depends on regional context. Gardener reports tell us that they are challenged by, but responding to, the climate changing around them by changing their watering practices and to a lesser extent by changing the plant species they select to grow. Rather, gardeners state they continue to select plants that they think are able to provide food and usable products. However, the evidence of the species recorded growing in plots shows that temperature variability does influence the plant composition of plots in the region with more temperature variation, suggesting that plant survival and species distribution is related to temperature and not just people's preferences for plant attributes. Thus although gardeners may be able to overcome some temperature effects by adjusting their watering behavior to maintain the plants they consider important for food provisioning, gardeners are not able to completely mitigate these effects within climatically variable regions and plant species richness continues to be shaped by climatic drivers. In the following discussion, we explore these two related findings from our work: 1) temperature variability and plant species richness in gardens, and 2) their relationship to gardener beliefs, preferences and behaviors.

4.1. Temperature variability and plant species richness in gardens

Landscape context (bioregion) is a significant determinant of community garden temperature variability at both the garden scale and plot scale. Gardens and plots in the Gippsland Plain, a bioregion with more natural land cover, experience significantly larger fluctuations in daily temperatures than gardens in the Victorian Volcanic Plain, a bioregion with greater impervious surface cover. Indeed, gardens surrounded by more impervious surface had lower temperature variability (or higher temperature stability). However, daily temperatures within these regions are similar, suggesting that the temperature fluctuations are more extreme when in natural surroundings. Urban heat island effects could be stabilizing daily temperatures in gardens, as heat is absorbed and retained by impervious surface throughout the day and released slowly in the night to reduce large temperature fluctuations (Grimm et al., 2008; Oke, 1973). Higher temperatures from urban heat islands have been found within similarly structured urban community gardens in comparable urban regions in the USA (Lin et al., 2018). In Melbourne, urban heat island effects within green spaces are documented (Torok et al., 2001) but are neighborhood context dependent (Coutts et al., 2007). Interestingly, at the garden scale, local factors including greater grass ground cover and the number of trees and shrubs did not have strong effects on temperatures in gardens (i.e., were not strong predictors in our models), even though greater grass ground cover (Huang et al., 2008) and tree densities can significantly cool

urban green spaces (Berry et al., 2013). This could be because grass (turf) and urban trees are often not irrigated in Melbourne in contrast to other urban environments (e.g., Southwestern USA). Thus if and how local or landscape-scale land cover affects urban garden microclimate may be very dependent on regional context.

A species area relationship is strongly driving urban garden plant species richness at the garden scale, and at the plot scale in regions where temperatures are more stable (Victorian Volcanic Plain). Garden-scale plant species richness accumulates with garden size (i.e., a proxy for cultivation area), and size could be weakening the relationship of temperature variability on total species richness on the garden scale, a relationship that we found at the plot scale only in the region where temperatures are more variable. Garden size is correlated with the number of plots and the number of gardeners, suggesting that gardens with more gardeners and therefore more diverse management practices have higher plant species richness (Kendal et al., 2010). We also observed that the larger gardens had more communally managed cultivated areas that are often cared for by a group of gardeners, likely increasing species richness and chances of plant survival. At the plot scale, gardeners may have more species in their plots if they have more space to cultivate and experiment with if they are less challenged by regional temperature variability that could affect more sensitive plant species. This may be due to differences in an individual's management and capacity to maintain high plant richness in climate extremes (discussed below). Plant richness in urban home gardens is similarly positively correlated with increasing garden size (Loram et al., 2008; van Heezik et al., 2013), and home gardens have similar high species richness to these allotment gardens (Clarke, 2014; Loram et al., 2008; Smith et al., 2006) including gardens in the Gippsland Plain bioregion (666 species vs our 655 species) (Threlfall et al., 2016). These studies in home gardens have found comparable species accumulation patterns from sampling efforts to ours. For example, Loram et al. (2008) documented >1000 species within home gardens across five urban regions in the UK; however, their species accumulation curves were far from saturation after 120 samples. Clarke (2014) found that the total 278 observed species in 104 home gardens in Los Angeles, California, USA did not asymptote, even after extrapolating to 200 gardens. Along with these studies our findings further the argument that urban gardens are diverse in plant species and research has not captured all of the agrobiodiversity that they harbor (Galluzzi et al., 2010).

4.2. Gardener planting decisions and watering behavior

Gardeners in this study strongly agree that temperature and natural precipitation influence the way that garden plants grow, and strongly agree that the climate is changing. The gardeners state that climate changes in temperature and precipitation are challenging their garden management. In response, gardeners often try to mitigate climate extremes by adjusting watering behavior in efforts to support plant survivorship and crop production – gardener's state that they visit their garden more frequently during extreme heat events to provide supplemental irrigation to plants. Although we did not directly measure water use, increased watering frequency suggests that gardeners are likely using more water to maintain their plants based on what they think their plants need. Water use monitoring in community gardens in California, USA found that gardeners water longer and use more water when temperatures are higher (Lin et al., 2018), and gardener water use behavior is similarly influenced by the perceived water requirements of the plants that they are growing. Although gardeners readily adjust their water use behavior to climate changes, the majority of gardeners do not adjust plant selection to climate/temperatures. Rather, gardeners select plants that provision food or usable products: food provisioning was three times more important of a plant attribute to gardeners than water use/needs or other cultural factors. This suggests that plant species in gardens are driven by plant traits associated with food production (e.g., higher flower and fruit set) and ecosystem services rather than plant traits associated with water needs or temperature thresholds. This is similar to reported preferences for ecosystem service-based traits of urban trees (Pataki et al., 2013). However, as mentioned above, we have evidence that plant survival is nevertheless related to climate because plant species richness declined with increasing temperature variability in the garden plots in the bioregion with more variable temperatures. Thus water use behavior may be able to mitigate some temperature effects to maintain plants, but not entirely, and temperature variability can remain as an environmental filter of plant survival if there are strong regional climatic effects on the local climatic context (Williams et al., 2008). A garden in a more variable local climatic context versus one in a more stable local context could have higher chances of plant mortality if gardeners in those gardens are not able to quickly respond to, for example, temperature extremes. Indeed, the high abundance and distribution of "alien" crop species and rare species including ornamentals in home garden systems are explained by gardener management and supplemental irrigation (Loram et al., 2008; Clarke, 2014). In sum, our study suggests that plant species presence and species abundance within urban gardens are mediated by gardener preference for specific plant attributes, ability of gardeners to adjust water use behavior to climate changes to prevent plant mortality, and landscape- and plot-scale variability in temperatures.

5. Conclusion

The relationships between landscape, temperature variability and gardener behavior delivers perspective on the future sustainability and planning of urban gardening. Because reported gardener resource use behavior is largely informed by temperature and precipitation fluctuations and extremes, our results suggest that gardening in more urbanized areas may have some surprising food production benefits for urban gardeners in comparison to the peri-urban fringe (here the Gippsland Plain). More stable temperatures within the urban core regulated by regional drivers may accommodate productive, species diverse and sustainable fruit, flower and vegetable gardening to provision food and well-being benefits provided the space to do so. From an urban sustainability and urban planning viewpoint, as cities like Melbourne densify in structures to meet population growth, urban gardens should be better incorporated into the built fabric of cities through environmental and social reform efforts. Urban gardening can support crop diversity to improve food security, and could have climate mitigation potential in the city (Lovell, 2010; Piacentini et al., 2014). In conclusion, urban gardens are diverse agroecosystems that are shaped by individual gardener management and as well as by landscape-scale environmental factors, and this can likely affect resource use in the city. The relationships among environmental factors, human decision making, biodiversity and subsequent water use should be carefully considered in city climate adaptation plans.

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Conflict of interest statement

The authors have no conflict of interest or competing interests to declare.

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